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NASA SPACE VEHICLE DESIGN CRITERIA

PANEL FLUTTER

VOLUME III: STRUCTURES

PART B: LOADS AND STRUCTURAL DYNAMICS

CHAPTER 1: GENERAL CRITERIA

SECTION 2: PANEL FLUTTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform design criteria for space vehicles. Accordingly, criteria are being developed in five areas of technology, outlined as follows:

Volume I — Environment
Volume II — Material Properties and Processes
Volume III — Structures
Volume IV — Stability, Guidance, and Control
Volume V — Chemical Propulsion

The individual components of this work are regarded as being sufficiently useful to justify publication separately in the form of monographs as completed. This document, Section 2 of Volume III, Part B, Chapter 1, is one such monograph. The planned general outline of Volume III is set forth on page ii.

These monographs are to be regarded as guides to design and not as design requirements, except as may be specified by NASA project managers or engineers in formal project specifications. It is expected, however, that these documents, revised as experience may indicate to be desirable, will eventually become uniform design requirements for NASA space vehicles.

Comments from addressees concerning the technical content of the monographs are solicited. Please address such comments to the National Aeronautics and Space Administration, Office of Advanced Research and Technology (Code RVA), Washington, D. C. 20546.

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PLANNED OUTLINE OF VOLUME III: STRUCTURES

Volume III: Structures
Part B: Loads and Structural Dynamics
Chapter 1: General Criteria

SECTION 2: PANEL FLUTTER

2.1 INTRODUCTION

Panel flutter is a self-excited oscillation of the external surface of a vehicle caused and maintained by the aerodynamic, inertia, and elastic forces of the system. The occurrence of flutter in a particular panel configuration depends on the stiffness of the panel, local Mach number, local dynamic pressure, in-plane flow angularity, thermally induced and mechanically applied loads, and pressure differential across the panel.

The amplitude of the motion of an unstable panel will increase with time, although the amplitude may be limited because of system nonlinearities.

Panel flutter of a catastrophic nature (rapid-divergence type) must be avoided. The limited-amplitude type of flutter may be tolerated, provided the flutter amplitude and duration are such that structural failure due to fatigue, or functional failure of equipment attached to the structure, is not expected to occur.

2.2 STATE OF THE ART

The present state of the art does not admit of design criteria that may be used without qualification. Even wind-tunnel investigations of hardware items for specific vehicles require the use of larger flutter margins than is the case for classical wing flutter because of uncertainties regarding many of the parameters which affect panel flutter boundaries. Although much theoretical work has been published (summarized in ref. 1), the theoretical predictions have shown generally poor agreement except for the simplest panel configurations. In addition, attempts at correlation of the available data, from both flight and wind-tunnel investigations, have shown excessive scatter (refs. 2 and 3). Such scatter has resulted from oversimplification of the very complex phenomenon, as well as from lack of precise definition of flight or test conditions. Recent theoretical and experimental investigations, on the other hand, have done much to delineate the important parameters and to define the variables which must be controlled to permit wind-tunnel simulation of the flight environment.

The development of improved analytical methods for description of the aerodynamic forces and the recognition of the importance of panel edge restraints and boundary conditions have substantially advanced the state of the art. Linearized three-dimensional potential flow theory, which should be valid in the low supersonic speed range ($M > 1.1$), has been applied by Zeijdel (ref. 4) to an array of rectangular panels and by Cunningham (ref. 5) to single finite panels, using a numerical-integration box method. Such methods show promise of reliable predictions when the boundary layer is thin and the panel and its environment are adequately described. In reference 6 Fung has discussed the important influence of the viscous boundary layer. In reference 7 boundary-layer thickness is shown to have large effects on cylindrical shell flutter. McClure (ref. 8), using a viscous fluid analytical model, has obtained remarkable improvement in agreement of theory with experiment for flat plates at low supersonic speeds in one instance.

Potential-flow linear piston theory greatly simplifies flutter analyses and appears to give reasonable results for simple unstressed panels at Mach numbers greater than 1.5. By means of this simpler aerodynamic theory, the effects of flow angularity in the plane of the panel have been analyzed by Kordes and Noll (ref. 9) and Eisley and Luessen (ref. 10) for isotropic panels, and by Bohon (ref. 11) for orthotropic panels. Bohon and Dixon (ref. 12) have shown that reasonable predictions of flutter for unstressed corrugation-stiffened panels are not obtained without considering the transverse deflectional stiffness of the panel supports. The effect of midplane stress for panels loaded in compression to and beyond the point of buckling has been demonstrated experimentally for flat rectangular panels with length-width ratios from 1 to 10 (refs. 13 to 18). The principal areas of agreement and disagreement between experiment and calculations based on small-deflection theory and modified piston theory have been pointed out by Guy and Dixon (ref. 19) for thermally induced stress levels below buckling. Analytical results for initially flat, rectangular panels in a postbuckled condition, obtained by Fralich (ref. 20) with the Von Karman large-deflection equations, have shown qualitative agreement with experiment for nearly square panels. Reference 21 has shown the importance of panel edge restraint and boundary conditions in the flutter of panels at the point of buckling and has related this flutter boundary to buckling parameters.

In summary, recent theoretical and experimental investigations have identified many of the parameters which are important in the study of panel flutter. While much remains to be learned, panel flutter investigations may now be put on a rational and systematic basis. Future studies should therefore lead to the collection of data useful for a more accurate assessment of flight flutter margins.

2.3 CRITERIA

The external surface of space vehicles shall be free of destructive flutter at all dynamic pressures up to 1.5 times the maximum local dynamic pressure expected to be encountered at any Mach number within the normal operating envelope and during aborts from the normal operating conditions.[1] Destructive flutter is considered to be flutter of a catastrophic nature (rapid breakup of structure) and limited-amplitude flutter which will cause fatigue failures of any structural panel or cause functional failure of equipment.

Tests should be conducted on at least one panel (with its support system) of each structural type on the vehicle. Tests should include, but not be limited to, simulation of panel in-plane flow angularity, local Mach number, local dynamic pressure, thermally induced and mechanically applied loads, and pressure differential across the panel. Where previous test data exist for panels of similar structural configuration and edge support conditions, such data may be considered acceptable in lieu of further tests.

Instrumentation for detecting panel flutter should be installed on one or more vehicles during development flight tests.

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[1]The factor 1.5 results from analyses of experimental data available to date. These data have been correlated by using the panel flutter parameter

$$\left(\frac{q}{\beta E}\right)^{1/3} \frac{l}{t}$$

where

q dynamic pressure

$\beta = \sqrt{M^2 - 1}$

M local Mach number

E Young's modulus

l panel length in direction of flow

t panel thickness

This flutter parameter indicates that flutter boundaries are extremely sensitive to changes in panel thickness, and whereas a meaningful flutter margin might be specified in terms of panel thickness, the usual practice of applying a factor to dynamic pressure has been followed.

Experience has indicated that a 15-percent margin is needed on the panel flutter parameter to cover adequately the experimental scatter on panel flutter boundaries. A 15-percent margin on the panel flutter parameter is equivalent to $(1.15)^3$, or 1.5, on dynamic pressure.

2.4 RECOMMENDED PRACTICES

2.4.1 ANALYSIS

Although recent theoretical work shows promise, experimental verification of analytical procedures for prediction of panel flutter has not yet been obtained in all speed ranges. Hence theoretical flutter analyses should be restricted to use in identifying the most critical panel of each structural type for experimental evaluation. Recommended procedures for selecting critical panels in each of two categories are given in paragraphs 2.4.1.1 and 2.4.1.2.

2.4.1.1 Panels Not Subject to Compression or Shear of the Middle Plane

Experimental correlation envelopes such as those published in references 2 and 3 may be used for rectangular panels exposed to uniform flow parallel to one edge. For such panels at Mach numbers above 1.5 analytical methods that are applicable to the given configuration and that employ modified piston-theory aerodynamics are recommended (ref. 12). The effects of flow angularity in the plane of the panel should be analyzed separately and the resulting change superimposed on the results obtained for zero flow angularity. The effective thickness and width used for nonisotropic panels should be the dimensions of an equivalent isotropic plate having the same important stiffness characteristics as the actual panel. For corrugation-stiffened panels such an analysis must include the transverse deflectional stiffness of the panel supports at the ends of the corrugations (ref. 12).

2.4.1.2 Panels Loaded in Compression or Shear

Analytical methods that are applicable to a given configuration and include the effects of midplane loads may be used. Estimates should be based on the juncture of the unbuckled panel flutter boundary with either the postbuckled flutter boundary or the static buckling boundary (see ref. 19) or on the "transtability value" (ref. 21). When such estimates are based on linear theory, results will indicate that an infinite stiffness is required to prevent flutter for many panel configurations. However, excessive stiffness requirements may be avoided by changing the length-width ratio or the edge support conditions of the panel. Either calculated or measured vibration modes may be used in the analysis, provided that the mode in which the panel ultimately buckles is included (see refs. 11 and 21). Linearized piston-theory aerodynamics is permitted above a local Mach number of 1.5. At lower Mach numbers aerodynamic unsteady theory should be used.

2.4.2 WIND-TUNNEL FLUTTER TESTS

Flutter tests should be made on a sufficient number of representative full-scale panels to insure freedom from destructive flutter except where freedom from such flutter has been demonstrated on the basis of existing experimental data. In flutter tests, local flow conditions over the panel for all vehicle flight attitudes, and the panel edge loading and boundary conditions expected in flight, should be simulated. The magnitude of the pressure differential Δp across flat panels should be maintained at values smaller than the minimum flight values for all tests. For panels with curvature, the pressure difference should equal or exceed flight values if the direction of loading is toward the axis of curvature. For thermally stressed or mechanically loaded panels, the loading should be applied until the panel buckles.

2.4.3 GROUND TESTS

Frequency and nodal lines should be measured by vibration tests for panels selected for wind-tunnel evaluation. For panels subject to thermal stress or applied in-plane loads in flight, particularly those that are non-isotropic, it is desirable to attempt measurement of vibration and buckling modes for substantiation of preliminary flutter estimates and to aid evaluation of wind-tunnel test results. It is important to simulate the edge restraint and boundary conditions, as well as the thermal environment, which should duplicate the appropriate heating or cooling rates and temperatures of flight.

2.4.4 FLIGHT TESTS

Instrumentation should be installed on the first vehicle to be launched at high dynamic pressure in order to monitor the most flutter-critical panels and to confirm the panel flutter stability. Instrumentation to measure frequency of vibration and temperature is essential, while instrumentation to measure strain and deflection amplitudes is desirable.

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